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Life Cycle Assessment of Smithy Training Processes

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Abstract

Sustainability has long been a part of social responsibility. Today sustainability is a part of the core business strategies. It is viewed with environmental and economic perspectives. India, being a manufacturing hub has to deal with the problem of environmental and social impacts of these manufacturing operations. Smithy operations have large adverse impact on the environment. Life-cycle analysis should be applied to alleviate and reflect environmental burdens of this process. This paper presents the basic concepts of sustainability and life cycle analysis. A study has been carried out in the context of smithy training process. Software tool Umberto 5.6 with eco-invent 2.2 database is used for analysis. The effect of smithy training in term of acidification potential, climate change, eutrophication potential, freshwater aquatic, eco-toxicity, marine aquatic eco-toxicity, human toxicity, ionizing radiation, land use, photochemical Ox (smog), and stratospheric ozone depletion.

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Keywords: Sustainability; Life cycle assessment; Smithy training.

1. Introduction

Sustainability is a quality that permits to preserve, keep, maintain something; when something is sustainable, it is able to be kept (Ciceri et al. 2009). The topic of environmental impact has received increasing importance mainly due to the increasing sustainability awareness and concerns. Manufacturing firms consume natural resources in highly unsustainable manner and release large amounts of greenhouse gases leading to many economic, environmental, and social problems from global warming to local waste disposal (Sangwan, 2011). It makes sense to look at sustainability from the very beginning of the process including raw material selection and extraction, design, manufacture, use, end of life, i.e. throughout the life cycle of the product. This paradigm of taking care of environment throughout the life cycle of the product is termed as eco-design. It can be described as a simple

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application of life-cycle thinking from a design perspective, and the benefits of doing so can includes cost savings, legislative and regulatory compliance, and customer satisfaction. If organization wants to design a process or a product with sustainability principles in mind, it needs to consider its eco-design and then minimize the biggest environmental impacts identified from this analysis. Manufacturers are using various manufacturing processes to produce goods according to the customer needs. In manufacturing processes forging is an important and the oldest technology of manufacturing predominantly used in automotive and aerospace industries. The concept of heating the metal and hammering it to get the desired shape is being practiced across the globe from the late 19th century. However, with growing environmental concerns, it has become imperative for a quantitative assessment of its impact on the environment. This could be done through a Life Cycle Assessment (LCA) of products.

Now a days, Universities and educational institutions should also approach sustainability in a more holistic way because they play a vital role in educating their students and providing the community with graduates who have the knowledge and skill to transform their workplace and make the world a better place to live. These technical educational universities must impart knowledge of the current and latest technological developments in the industry to make students industry ready. Lozano (2006) has mentioned in his paper that universities have the opportunity to elevate the importance of sustainability through scholarly and public disclosure. Universities throughout the world have contributed to sustainability through "greening of campus", offering courses on sustainability, or contributed to specific research activities. However, innovative thinking is really required by the universities. According to the report published by All India Council for Technical Education (AICTE) more than 3 million students are registered for the technical education throughout India. This data reflects the importance of the study. It calls for training students in latest technologies in various fields and *Workshop Technology* is one of them. As a part of curriculum of Workshop Practices in BITS Pilani University, students of various engineering discipline are provided demonstration and practical in smithy shop. The motivation for this research work originates from one such initiative put forward by BITS Pilani, India through the creation of a course on "Sustainable Manufacturing" that imparts concepts of sustainability and life cycle assessment. The aim of present work is to analyze the environmental impacts of smithy machine shop.

2. Life Cycle Assessment

Life Cycle Assessment is a scientific quantitative evaluation technique for assessing environmental impacts and resource consumption for producing a product or for a process from the raw materials extraction, processing to final disposal, which is the entire life cycle (from cradle to grave) (Klöpffer and Walter., 1997). LCA can be used as a technical tool to evaluate environmental consequences of a product, production process, packaging or any activity across the entire life cycle of a product or service (Sagnwan, 2006). Nowadays LCA is widely used in the environmental impact assessment of various products like flash drive, computers, wind turbine, automobiles (MacLean, et al., 2003), televisions, monitors and other products (Bhakar et al., 2013) and have shown positive results in understanding the environmental impacts of these products (Martinez et al., 2009). Metal working is a major source of environmental pollution and in recent years some researchers have used LCA to study the environmental impact of metal working and machine tools (Song et al, 2010). Most of the research about environmental impact of machine tools has been in the industrial application of machine tools. This study emphasize on the very basic of the metal working and its machinery. LCA begins with the gathering of raw materials from the earth to create the product and ends at the point where all materials are returned to the earth.

LCA deals with all stages of a product's life from the perspective that they are independent. It enables the estimation of cumulative impacts on environment resulting from all stages of product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation and product disposal, etc.). LCA as a process is a systematic, phased approach and consists of four components, as guided by the International Standards Organization (ISO) 14040 and 14044 series standards: goal and scope definition, inventory analysis, impact assessment, and interpretation as shown in figure 1.

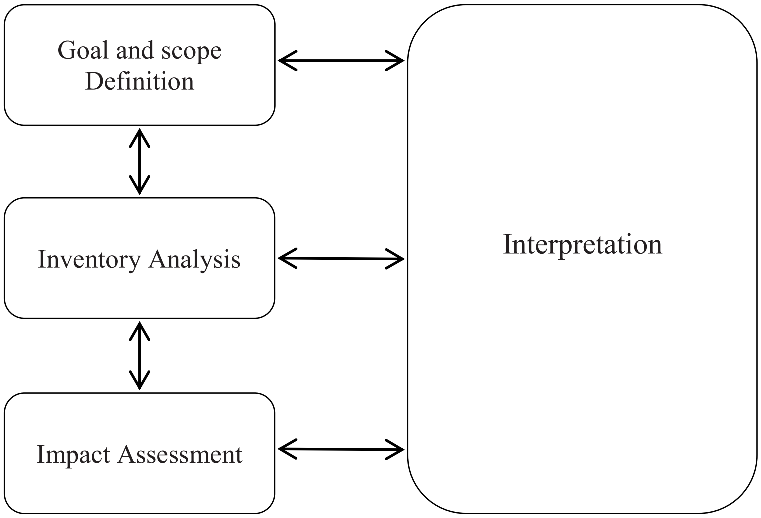

Figure 1 Phases of LCA (Source: ISO, 2006)

This paper presents the LCA methodology used to assess the environmental impacts associated with the smithy section of an educational workshop in training of undergraduate students every year. LCA has been performed on every tool, machine and material used in the smithy section, considering the three distinct phases- extraction, service and disposal. The analysis was conducted using Umberto 5.6 software, eco-indicator 99 and CML 2001. Umberto is a software tool for material and energy flow analysis and life cycle assessment. CML (midpoint) (Centrum voor Milieuwetenschappen) and eco-indicator 99(endpoint) are useful evaluation methods to determine the environmental impacts. The next section provides the LCA methodology.

3. Materials and Methods

3.1. Goal and scope definition

Aim of the study

To find the environmental impact caused by the operations associated with smithy shop demonstrations and practical during the training of the undergraduate engineering students in term of acidification potential, climate change, eutrophication potential, freshwater aquatic and sediment eco-toxicity, marine aquatic and sediment eco-toxicity, human toxicity, terrestrial eco-toxicity, ionizing radiation, land use, malodors air, photochemical Ox (smog), depletion of abiotic resources and stratospheric ozone depletion.

Scope of the analysis

Every year a total of 850 students, combined into few groups get training in the smithy shop demonstrations producing parts. The machines of the shop have been assumed to have a life of 50 years catering to 850 students per year.

Functional Unit

The impact generated is considered per student, per year due to the smithy shop demonstrations and practical training. The entire analysis limits itself to this functional unit. The unit includes effects of material extraction, fuel consumption and disposal. This paper limits itself to the environmental impact associated with these stages and does not consider the total impact that might occur due to various other operations (project and consultancy) carried out in tandem in the smithy shop.

3.2. System Boundary

The analysis considers the entire life cycle of the two products and the machines involved. The entire life cycle is composed of raw material extraction, transportation of the equipments, transportation of the materials, manufacturing of the equipment, manufacturing of the products, and disposal of the products. However, transportation and manufacturing of equipments are not included in the system boundary as shown in figure 2.

The impact due to the equipment is negligible in the use phase. Raw material extraction, disposal and use of electricity are the processes which have considerable impact and have been thoroughly covered in the paper. Besides the main sequential processes, the analysis also includes the impact due to the fuel (coal) consumed in the process. The analysis of the manpower and other energies is not a part of the system boundary considered. In terms of electricity mix used for the study, it is prudent to mention here that that electricity mix for India is not available with database and is modelled on the basis of report of bureau of energy efficiency (A government of India Undertaking) for the mix of electricity production in India. It also reflects that in Indian electricity mix, approximately 67.2% of the total electricity is generated by coal based power plants.

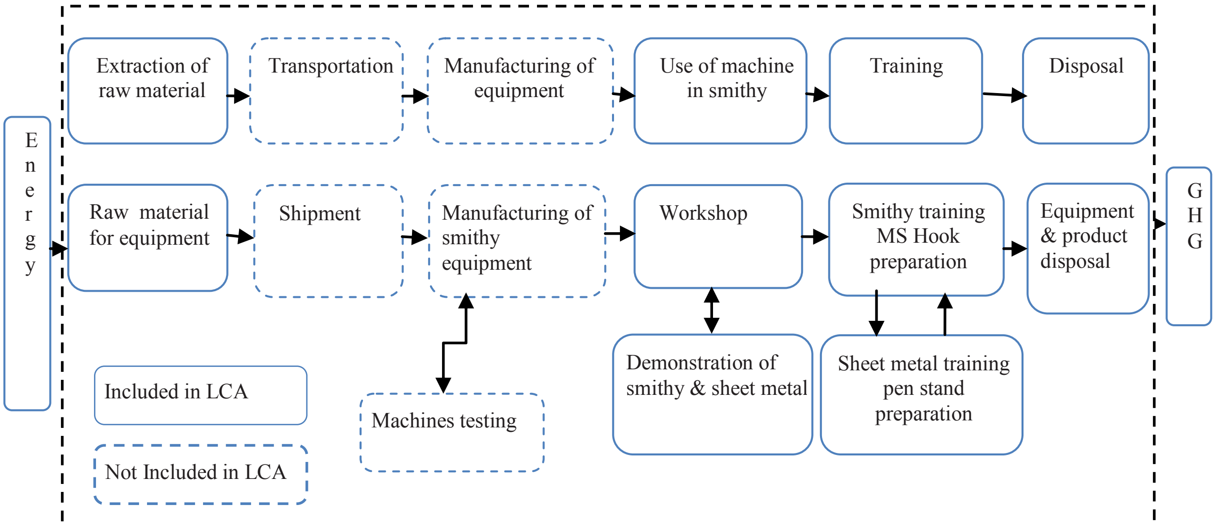

Figure 2 System Boundary of Smithy and sheet metal training process

3.3. Life cycle inventory

The compilation of primary inventory data was carried out by observing closely the training process. Estimations of the amount of material were done either by actual dimensions or weight measurement wherever possible, or by using the equipment manual/brochures and available literature on the internet of the similar models.

Possible and feasible, average or typical process-specific data were collected, by performing time study at the workshop. To model the environment impact of smithy shop, the data obtained both from the primary and secondary data bases have been combined. Another challenge faced during the study is to match the actual material available with the database incorporated in the Eco-invent database. All materials as observed in the study are not exactly available in the database. Therefore, following assumptions have been made during the study:

- Machines are assumed to be made of steel and cast iron, and hand tools are assumed to be of either hardwood or steel.
- For the motors in the machines, only copper winding has been explicitly considered.
- Disposal of refractory bricks isn't considered because of negligible impact on environment.

The detailed inventory list for the study is compiled in table 1.

Table 1 Inventory list for smithy training process

S.No.	Material	Equipment in which the material is used	Quantity (kg)	Source
1.	Tin	Tin boxes for sheet metal	0.164705882	Workshop store
2.	Hard coal	Fuel in furnace, hammers	0.588235	Workshop store
3.	Cast Iron	Anvil, swage block, power hammer, sheet cutter, rolling machine, leg vice	0.06	Manufacturer of equipment
4.	Ferrochromium high carbon	Anvil, fuller tool, shear strips, hammers, power hammer, sheet cutter	0.0133411	Manufacturer of equipment
5.	Mild steel	Furnace, MS hook job pieces, furnace tool, tongs, hammers, chisel, power hammer	0.01956	Workshop store and Manufacturer
6.	Solder material	Soldering purposes in pen stand making	0.00235	Supplier
7.	Flux Material	Soldering purposes in pen stand making	0.00235	Supplier
8.	Refractory bricks	Open hearth furnace	0.0042353	Manufacturer
9.	Sawn timber	For initiation of combustion of coal	0.00023529	Workshop shop floor

3.4. Life cycle impact assessment using Umberto 5.6 software

The whole smithy process material flow model is developed in the Umberto 5.6 software as shown in figure 3. First, the materials were segregated in different basic materials and than in extraction phase of the model transition for all the materials are specified. After this disposal and extraction of all the materials in the model are brought under the transition 'share of equipment per student'. This transition is made concretely to represent all equipments in form of single equipment used by the students. As mentioned above Indian electricity mix that is modeled earlier is incorporated in the 'use' phase of the model in term of energy consumed. For the impact assessment, the well-known Centrum voor Milieuwetenschappen (CML) methodology and Eco-indicators'99 were used.

Eco-indicator 99 is an endpoint impact assessment method with top-down approach, which allows the environmental load of a product to be expressed in a single score. It is designed around three damage categories of human health, ecosystem quality and resources. The methodology is defined in three spheres: *technosphere, ecosphere* and *valuesphere*. Life cycle model is constructed in *technosphere* resulting in inventory table, whereas modeling in *ecosphere* is used to link the inventory table with three damage categories and finally *valuesphere* modeling is used to weight the three endpoints to a single indicator. However CML is a midpoint assessment method and it measures the environmental impacts in fifteen different categories of acidification potential, climate change, eutrophication potential, freshwater aquatic eco-toxicity, freshwater sediment eco-toxicity, human toxicity, marine aquatic eco-toxicity, marine sediment eco-toxicity, terrestrial eco-toxicity, ionizing radiation, land use, maladours air, abiotic depletion, photochemical (smog), and stratospheric O_3 depletion.

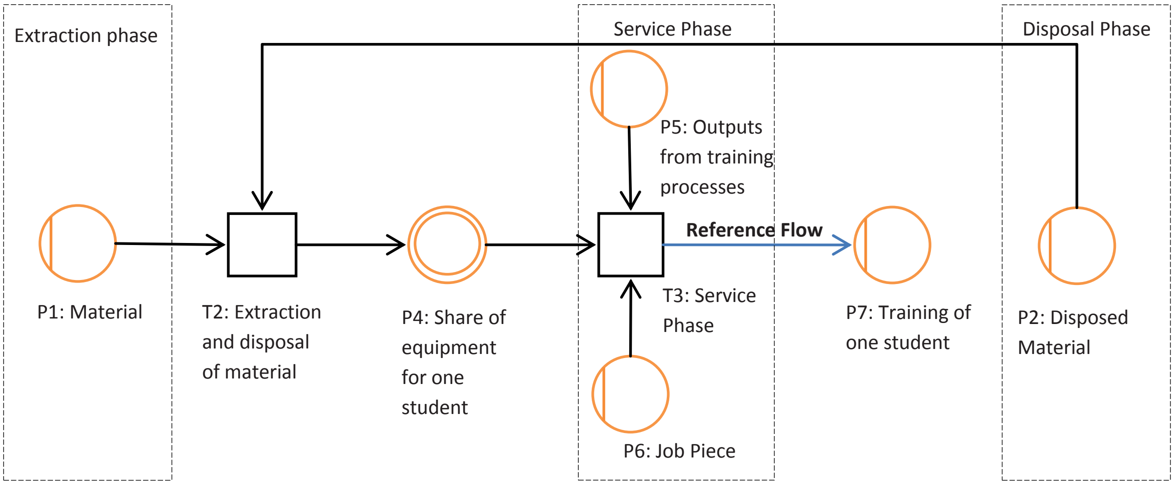

Figure 3 Basic flow diagrams for the modeling of the training process

4. Results and Discussion

The results of the impact assessment of the complete life cycle of a smithy and sheet metal training process is shown in table 2, it is described in the eleven categories (other four categories were found insignificant for the present case) assessed by the CML method and results from the Eco-indicators 99 valuation method are shown in table 3 and figure 4. As equipments are very old, so manufacturing and transportation phase of equipments are not considered in the study.

Table 2 CML Life cycle assessment results

Impact Category	Unit	Total	Extraction	Service	Disposal	Normalization factor	Impact per year	Normalized value	Percentage Normalized
Acidification Potential	kg SO_2-Eq	9.70E-02	1.44E-03	9.56E-02	4.94E-06	3.35E+11	8.25E+01	2.90E-13	4.82
Climate Change	kg CO_2-Eq	6.51E+00	1.85E-01	6.32E+00	6.70E-04	4.15E+13	5.53E+03	1.57E-13	2.61
Eutrophication Potential	kg PO_2-Eq	1.46E-02	4.33E-04	1.42E-02	9.67E-07	1.32E+11	1.24E+01	1.11E-13	1.84
Freshwater Aquatic Eco-Toxicity	kg 1,4-DCB	2.03E+00	1.38E-01	1.89E+00	4.91E-05	1.81E+12	1.72E+03	1.12E-12	18.60
Human Toxicity	kg 1,4-DCB	5.42E+00	3.71E+00	1.71E+00	2.38E-04	5.67E+13	4.61E+03	9.56E-14	1.59
Marine Aquatic Eco-toxicity	kg 1,4-DCB	7.54E+00	4.99E-01	7.04E+00	2.21E-04	1.90E+12	6.41E+03	3.97E-12	65.95
Terrestrial Eco-toxicity	kg 1,4-DCB	1.62E-03	5.23E-04	1.10E-03	1.12E-07	1.40E+11	1.38E+00	1.16E-14	0.19
Ionizing Radiation	DALYs	3.34E-08	9.38E-10	3.25E-08	1.29E-12	1.34E+05	2.84E-05	2.50E-13	4.15
Land Use	m2a	4.05E-01	7.09E-02	3.34E-01	1.17E-04	1.24E+14	3.44E+02	3.27E-15	0.05
Photochemical (Smog)	kg ethylene	7.58E-04	8.81E-05	6.70E-04	1.31E-07	8.69E+10	6.44E-01	8.73E-15	0.15
Stratospheric O_3 Depletion(20)	kg CFC-11-	1.88E-07	8.12E-09	1.80E-07	1.80E-10	6.01E+08	1.60E-04	3.13E-16	0.01
Total		**2.20E+01**	**4.61E+00**	**1.74E+01**	**1.30E-03**		**1.87E+04**	**6.02E-12**	**100%**

CML assessment is in different metrics of measurement. So it is required for the comparison, the emission categories should be in the same format or should have a normalized value. According to the ISO standards the reference system selection for normalization should consider the consistency throughout a year on the temporal and spatial scale. Hence, the values for normalization are calculated for yearly basis. Normalization of the impact categories gives better understanding of an impact. To obtain the normalized results characterization factor (final value of the emission) of the respective category is to be divided by the normalization factor provided. These normalization factors are provided by the same standard and are considering the emissions for one year. ISO standard also says that the emissions caused today but will be emitted in future should also be considered in the system. So, it represents a consistent reference system. The major contributors are marine aquatic eco-toxicity, freshwater eco-toxicity, acidification potential, ionizing radiation, global warming potential respectively. The graphical representation of the same is shown in the figure 4.

Table 3 Eco-indicators 99 Life Cycle Impact Assessment results

Category	Unit	Values	Impact per year	Percentage
Ecosystem quality	Points	0.0733	62.305	1.42%
Eco-toxicity	Points	0.029	24.65	0.56%
Human health	Points	0.469	398.65	9.13%
Resources	Points	4.53	3850.5	88.20%
Land occupation	Points	0.0176	14.96	0.34%
Fossil fuels	Points	0.017	14.45	0.33%

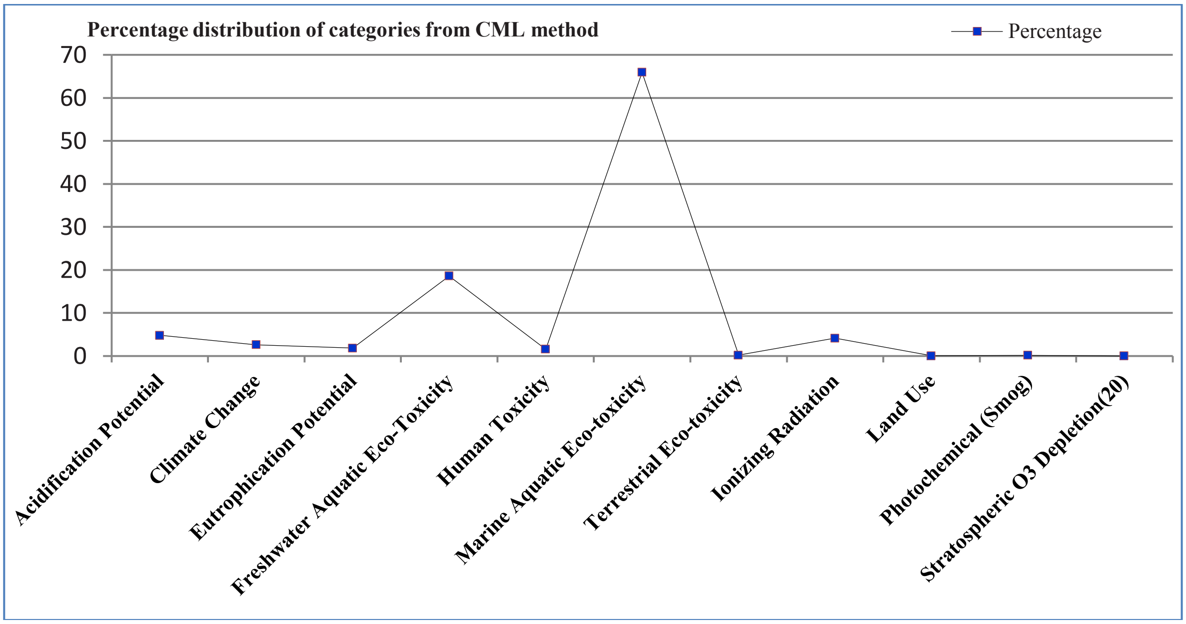

Figure 4 Distribution of the Impact categories with CML method

The impact assessment results from the Eco-indicator 99 method are in the same unit and need not to be normalized. A comparison of these results in term of the emission categories, it is found that resources depletion is the major contributor. Human health and eco-system quality, eco-toxicity are other major contributors as shown in figure 5. Eco-indicators provide brief description of the emissions whereas CML provides elaborate explanations for each category. After comparing the results sensitivity analysis is also performed on the basis of the respective methods categories and found that results obtained were of good quality and correct.

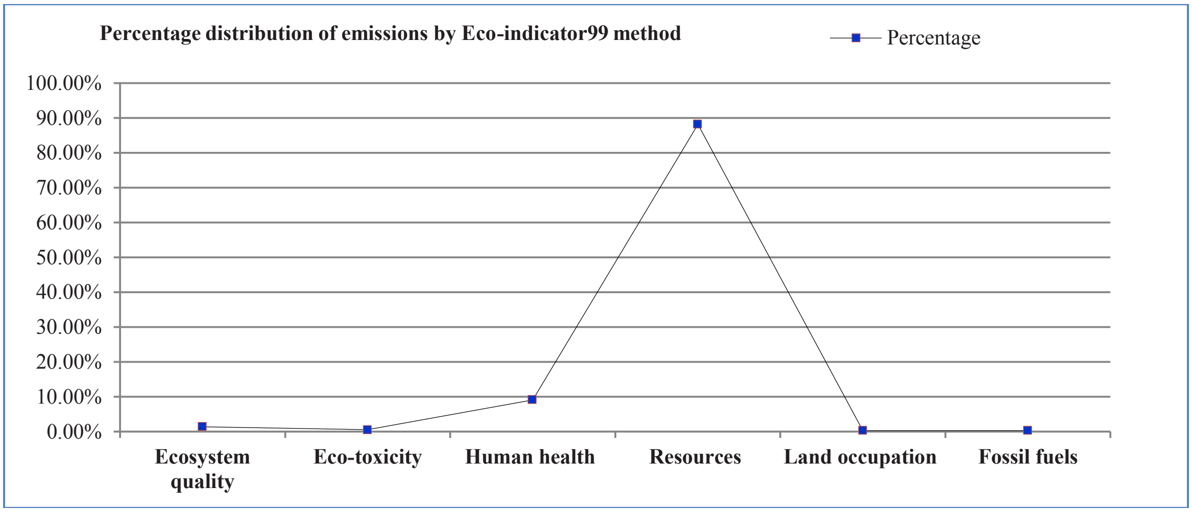

Figure 5 Distribution of impact categories on Eco-indicator 99 method

5. Conclusions

Life cycle assessment is found to be a useful tool for quantifying environmental emissions from the product and processes, and for identifying which stages of the life cycle are more responsible for these emissions. The production, use and disposal of low alloyed steel (Mild steel) has the most harmful impact on the environment in smithy training. Another notable contributor, especially in the service phase is the combustion of hard coal as fuel. The combustion of coal in the furnace is an inefficient process, leading to substantial wastages and high release of GHGs into the atmosphere. It is recommended that coal be used more efficiently, by better scheduling of the training periods, avoiding unnecessary initiation and termination of the combustion process every time a training period starts. A process which avoids the soldering reduces both the consumption of coal as well the consumption of solder. This would improve efficiency and simultaneously cut down on emissions in the service phase. Thus, proper energy and material balance system, combined with a little vigilance would contribute to substantially reduce the effect of the smithy training shop on the environment.

Adding life cycle assessment to the decision-making process provides an understanding of the human health and environmental impacts that traditionally is not considered when selecting a product or process. This valuable information provides a way to account for the full impacts of decisions, especially those that occur outside the plant and are directly influenced by the selection of a part/product or process. It should be remembered that LCA is a tool to better inform decision-makers and should be included with other decision criteria such as cost and performance to make a well-balanced decision in product design and waste management. This model can easily be extended for the industrial application by providing the appropriate inventory and process information.

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